Renewable and Sustainable Energy Reviews 41 (2015) 319–337

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

# Repowering: An actual possibility for wind energy in Spain in a new scenario without feed-in-tariffs

Antonio Colmenar-Santos *, Severo Campíñez-Romero [1], Clara Pérez-Molina [1], Francisco Mur-Pérez [1]

*Departamento de Ingeniería Eléctrica, Electrónica y de Control, UNED Juan del Rosal, 12 – Ciudad Universitaria, 28040 Madrid, Spain*

ARTICLE INFO

*Article history:*
Received 23 April 2014
Received in revised form
24 July 2014
Accepted 16 August 2014

*Keywords:*
Wind energy repowering
Profitability
Grid parity

ABSTRACT

At the end of January 2012, the Spanish government suspended the economic incentives for electricity generation facilities using renewable energy sources, including wind energy plants.

Spain maintains a high level of energy dependence that can only be reduced by applying measures to increase energy efficiency and using massive amounts of renewable sources. In addition, the target assumed by Spain, i.e., to have at least 20% of the primary energy to be supplied by renewable sources by 2020, has not yet been reached.

In Spain, wind farms, a number of which have been in commercial operation for over 15 years, offer a broad market appropriate for repowering. The use of more efficient wind turbines by means of repowering provides benefits to the electricity sector as a whole by optimizing the use of natural resources and facilitating the grid integration of the energy generated.

This paper analyses existing wind farms to quantify and characterize the market suitable for repowering. We discuss whether repowering is a valid alternative from the point of view of feasibility to enable the continuation of the integration of wind energy in the Spanish energy mix and whether this feasibility is sufficient when the energy generated is charged at the electricity market price in terms of grid parity. The results support that repowering is a profitable alternative and is often even better than the construction of new wind farms under certain conditions.



**Contents**



* Corresponding author. Tel.: +34 913 987 788.
*E-mail address:* acolmenar@ieec.uned.es (A. Colmenar-Santos).
[1] Tel.: +34 913 986 476; fax: +34 913 986 028.

http://dx.doi.org/10.1016/j.rser.2014.08.041
1364-0321/

## 1. Introduction

Law 54/1997 of the electricity sector [1] established a new regulatory framework, with the aim of guaranteeing the electricity supply with the highest quality standards and the lowest costs. This new framework was designed based on free competition with only the intervention of the administration to create the specific regulation.

From a retributive perspective, for the power plants under the special regime set up in the Law 54/1997,[2] the regulation established a system supported by a feed-in-tariff (FIT hereinafter) without time limits, which essentially consists of charging a bonus for renewable electricity fed into the grid over the price matched in the daily electricity market. As a second option, it was possible to choose a fixed tariff [2–4].

Under this stable regulatory framework and supported by an adequate legislation to facilitate the administrative authorization of the plants [5], at the end of March 2012, wind energy reached a degree of supply higher than 25% of the electricity demand in the Spanish market central bus-bars[3] [6].

Considering the significant level of primary energy dependence of Spain (75.6% in 2011), which is well above the average for the 27 countries in the European Union, the reduction to a value of approximately 55% at the end of March 2012 [7,8] indicates the success achieved in the implementation of the energetic mix of renewable energy sources (RES hereinafter), especially for wind energy [9–11], which exceeded a participation rate of 18% in the demand supply in 2012 [12].

In January 2012, the Spanish Government suspended the economic incentives for new-generation facilities based on RES, including wind energy [13]. Accounting for the fact that the targets established by the European Union (EU hereinafter) and the Spanish Government to cover 20.8% of the energy demand with renewable energy sources by 2020 have not yet been achieved [8,14], new strategies and regulatory policies are required to continue with the integration of RESs [15–17]. In this work, we examine wind energy as an important step toward attaining such a global objective; because of its degree of maturity, wind energy constitutes an actual possibility in a new setting without a FIT, thereby enabling scenarios that imply the lowest costs for the entire electricity sector [18].

The first wind turbine generators (WTG hereinafter) have been in commercial operation for more than 15 years and can be considered that they are entering the last stage of their nominal lifetime [19]. The repowering of wind farms (WF hereinafter) provides benefits to the electricity system as a whole [20], can improve the social and environmental impact [21,22] and may represent a reasonable option for the Spanish wind industrial sector to address the current critical situation [23].

This work is aimed at determining whether and under what conditions the repowering of a WF is a profitable alternative. We considered the feasibility of two possible alternatives to achieve a reasonable profitability for investors: maintaining the retributive system based on a FIT or charging the price determined in the daily electricity market (spot price hereinafter) for the electricity generated. The volume and the characteristics of the WFs that are suitable to be repowered are also determined.

Below, in Section 2, we analyze existing WFs to define, quantify and characterize the market formed by those suitable for repowering. Afterward, in Section 3, we estimate the expected production of a repowered wind farm (Rep-WF hereinafter) and the changes with respect to an old WF.

In Section 4, we define and estimate the costs of the facilities that form a WF and how these facilities could be reused in a Rep-WF to reduce the construction costs. In addition, the works for dismantling, waste treatment and valorization of the old WTG are also analyzed and considered.

In Section 5, we perform an analysis of the expected profitability of a Rep-WF, introducing a retributive proposal for the electricity generated based on the spot price and comparing the results with those obtained in case of retribution under the present scheme supported by FIT. Sensitivity analyses in relation to the most important parameters are included to consider the effect of their variations in the results.

Finally, Section 6 presents the conclusions of the study.

## 2. Determination of the market volume and its characteristics

### 2.1. Lifetime and financing

According to the standard IEC 61400 [24], a WTG should be designed for a lifetime of at least 20 years. During this period, with proper Operation and Maintenance (O&M hereinafter), the WTG will offer a level of mechanical availability[4] of nearly 100% during the first 5–10 years – presently, the typical values guaranteed by the manufacturers are approximately 97% – and over 90% for the remainder of its lifetime.

For most WFs, Project Finance was the method chosen by investors. With this method, the recourse to investor from the lenders is limited or even eliminated. The project itself, the WF in

[2] The article 27 of the Law 54/1997 defines the production of electricity in a special regime, such as that implemented in facilities up to 50 MW of installed power with the following characteristics. (a) The facility uses cogeneration or other electricity production methods associated to non-electric activities, and they suppose a high degree of energetic efficiency. (b) The facility uses as primary energy one of the renewable energies sources (RESs), biomass, or other type of biofuel, and the owner does not develop the production of electricity under the ordinary regime. (c) The facility uses non-renewable waste as primary energy.

[3] Energy fed into the grid from generators and international exchanges deducting the consumption required for generation and pumped storage.

[4] Mechanical availability is defined typically in a yearly period, as the percentage of time (year) in which the WTG is ready to produce electricity.

**Nomenclature**

*General*

| | |
|---|---|
| $C_P$ | coefficient of performance |
| FIT | feed-in-tariff |
| N-WF | new wind farm |
| O&M | operation and maintenance |
| P&C&G Grid | power, communications and grounding grid in the WF |
| Rep-WF | repowered wind farm |
| RES | renewable energy source |
| SCADA | supervisory control and data acquisition |
| Spot price | daily electricity market price |
| WTG | wind turbine generator or generators |
| WF | wind farm/wind farms |

*Generation and losses*

| | |
|---|---|
| CF | capacity factor (%) |
| $E_L$ | electrical losses (%) |
| $F_{AV}$ | mechanical availability factor (%) |
| $W_L$ | wake effect losses (%) |

*Financial*

| | |
|---|---|
| IRR | internal rate of return |
| NPV | net present value |
| $K$ | discount rate for NPV calculation |
| TDEP | depreciation period of the WF (years) |
| RPI | retail price index (%) |
| $CF_z$ | cash flow for year $z$ |
| $CFA_z$ | cumulative cash flow for year $z$ |
| NPV | net present value (€) |
| $z$ | ordinal indicating the number of years the WF has been in commercial operation, which is used in the IRR calculation |
| FL | financial leverage |
| VAT | value added tax (%) |
| TAX | incomes taxes (%) |

this case, will exclusively respond for repaying the debt. The incomes for selling the energy are the main guarantee, so these incomes must be predictable and sufficient [25,26].

For WFs, incomes can be estimated with a high level of confidence. Such an estimate is based on an adequate measurement campaign of the wind resources at the selected site, the retributive stability given by the regulatory framework during the entire commercial operation period and, finally, selecting an efficient and mature technology to ensure good functionality in the long term.

In the project finance method, the debt repayment period will depend on the cash flows generated by the WF. Therefore, to estimate this period, it is necessary to consider the special features of the project itself (its wind resource, the WTG, the costs, etc.). In general, periods in the range of 13–15 years are obtained [25].

From a financial approach, a suitable WF for repowering should have achieved a stage in which the investors had been able to repay the loan taken to finance the construction. However, from a technical point of view, the WTGs (of that generation) arriving to the end of their lifetimes will exhibit high failure rates, will require more maintenance and likely will suffer from a lack of relevant spare parts (generator, gearbox, blades, etc.).

Due to the evolution in the capital cost, the WFs first implemented in commercial operation were slightly more expensive to build [27]. This high capital cost considered separately could imply a negative impact on the repayment period; however, other factors also come into play. As will be demonstrated below, these WFs are located in regions of higher wind resources than the ones built later; in addition, the legislative evolution has allowed them to change to new frameworks, which are more advantageous in terms of retribution. Both of these facts imply a positive impact regarding incomes in the long term. For this reason, it is realistic to expect a lower repayment period that can be estimated in approximately 10 years,[5] which is shorter than the previously mentioned period. Thus, to characterize the repowering market, the considered WF must have an operation period equal to or longer than 13 years because during this period, it can be hoped that the incomes have allowed the investor to repay the debt incurred to finance the construction and have produced a positive cash flow for 3 years. In addition, the WTGs will not have arrived at the end of their lifetime but it is expected that a probable increase in the failure rates and the costs for O&M will occur to maintain a high level of mechanical availability [28].

### 2.2. Power of WFs

At the end of 2012, the WFs in Spain that were in commercial operation represented an installed power capacity of 22.6 GW [12]. The installation of the first units started in 1992, but the most significant growth has occurred since 1998 due to the stability provided by Law 54/97 [1] and subsequent regulations. This growth was also possible due to the evolution of WTG technology and the technical measures established to maximize their integration. For example, consider the forecasting of wind power generation [29,30] or the affiliation at control centers [31].

Fig. 1 shows the evolution of installed power in the period of 1998–2012 [12], which includes the years in operation. The first units, commissioned before 1999, were found to have a history of over 15 years in commercial operation.

The market volume of installed power for an operation period equal to or greater than 13 years (i.e., WFs installed up to the year 2000), would currently be approximately 2.3 GW. In addition, as shown in Fig. 1, the evolution of the yearly installed power will make this volume increase at a rate of approximately 1 GW per year.

### 2.3. Characterization of the power of WFs and WTGs

During the considered period of 1998–2012, approximately 1300 WFs were installed in the Spanish territory [12].

[5] In order to minimize the financial costs it is important to reduce the repayment period in which the investor must pay an interest rate for the borrowed money. This period is very sensitive with the electricity generated because more energy implies bigger incomes and the possibility for the investor to choose a smaller repayment period or reduce it during the commercial operation. By means of simulations carried out according with the cash-flows calculation method of

(*footnote continued*)
Table 9, an increase of around 10% in the yearly electricity generation can reduce the payback period between three and five years depending on other variables (i.e. the capital costs).

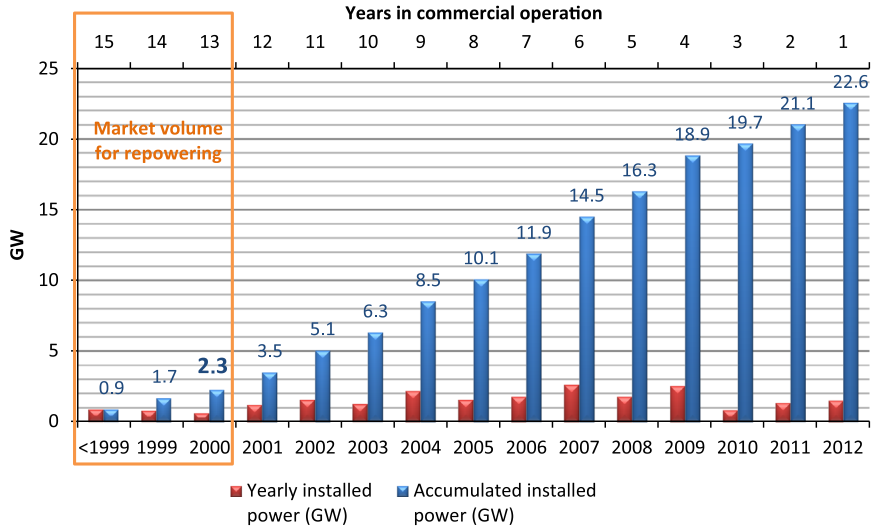


**Fig. 1.** Yearly and accumulated installed power in WFs and the number of years in commercial operation.
*Source*: National Energy Commission of Spain (CNE) [12]

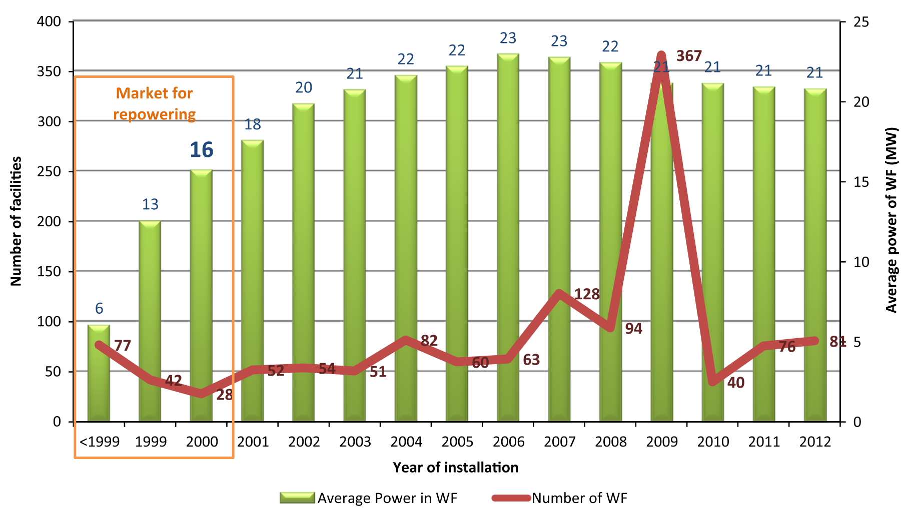


**Fig. 2.** Average power installed in WFs per year of installation.
*Source*: National Energy Commission of Spain (CNE) [12]

Fig. 2 shows the yearly evolution of the number of WFs installed and their average installed power. Note that the growth was regular and sustained, achieving a maximum in 2009 when 2.5 GW were installed in 367 WFs [12].

According to Law 54/97 [1], the capacity of the facilities under the special regime, including WF, cannot exceed 50 MW. Nevertheless, this maximum has yet to be approached; as Fig. 2 shows, the average installed power of WFs increased in the first years to become stabilized at approximately 20 MW.

Since the beginning of the deployment of wind energy, WTG technology has progressed to units that are more efficient and have a higher unitary rated power. This progress has encouraged the possibility to take more advantage of wind energy by both selecting the best places in the site – with a higher mean wind speed – and reductions in the construction and O&M costs, which is strongly influenced by the number of WTGs in the WF and by the use of these new WTGs [32].

Thus, WTGs have passed from the first units with a capacity of several hundred kilowatts to the current ones offered by the manufacturers with a rated power above 3 MW. Fig. 3 shows the evolution of the average rated power of a WTG installed up to 2012.

According to Fig. 2, for those WFs installed up to the year 2000, the value for the average installed power would be 16 MW. Nevertheless, for the purpose of characterizing a WF for repowering, an output of 18 MW was selected because it is the closest value to 16 MW which is a multiple of 2 and 3 MW and therefore facilitates the simulation with WTG of 2 and 3 MW.

Regarding the unitary rated power of a WTG, as shown in Fig. 3, for a WF that is 13 or more years in commercial operation, the typical value for the unitary rated power can be set between 559 and 651 kW.

### 2.4. Generation of electricity

Fig. 4 shows the annual evolution of the net WF capacity factor (CF hereinafter)[6] in the period of 1999–2012 differentiated by the

[6] The CF is defined, in a yearly period, as the percentage of the year during which the WF should have been working at nominal power to generate the entire production obtained in the year. The gross value (Gross CF) does not include the wake losses ($W_L$), the electric losses ($E_L$) up to the point where the electricity fed into the grid is measured, and the production losses due to the mechanical availability of the WTG ($F_{AV}$). The net value (Net CF) includes the effect of all the

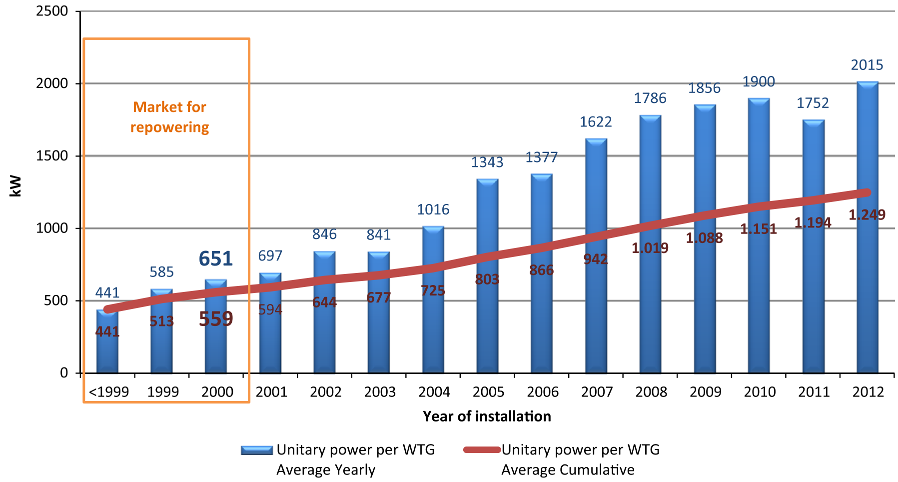


**Fig. 3.** Unitary rated power per WTG in a WF.
*Source*: Spanish Wind Energy Association (AEE) [23,33,34]

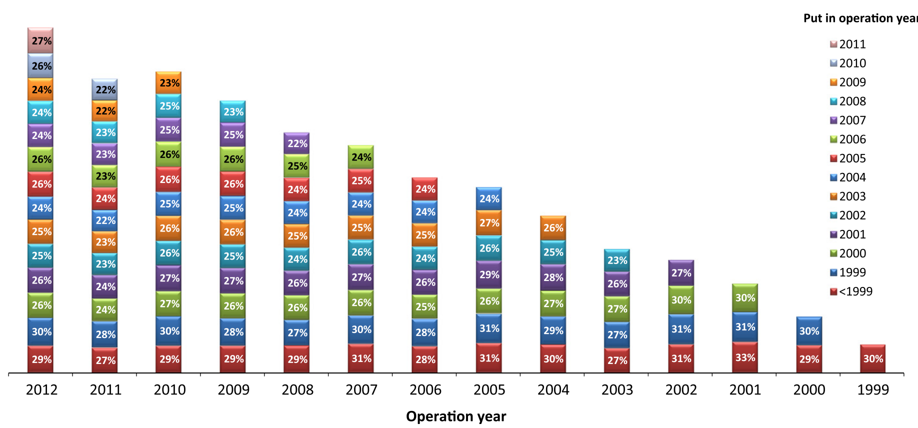


**Fig. 4.** Yearly capacity factor of WFs deployed during the year they were placed in operation.
*Source*: CNE [12]

year the WF was placed in commercial operation. Note that the WFs installed during the initial years continually offer the highest CF during the entire period.

In addition, Fig. 5 shows the temporary evolution of the yearly average net CF and its accumulated value for a WF in Spain, differentiated by the year they were placed in operation. The WTGs used in the first WFs were less efficient and less technologically advanced, besides considering that it is expected a relevant decline in their performance with age [28], one may conclude that the wind energy potential of the sites where the first WFs were built is substantially better than those of the later WFs.

By characterizing the WFs suitable for repowering, the average net CF considered for a WF with a minimum commercial operation period of 13 years is calculated and shown to be approximately 28% in Fig. 5.

### 2.5. *Characterization of WFs suitable for repowering*

Table 1 summarizes the results obtained from the characterization of WFs suitable for repowering that were described in the previous sections.

(*footnote continued*)
aforementioned losses (expressed as a percentage); therefore the relation between the Net CF and the Gross CF is the following:

$$\text{Net CF} = \text{Gross CF} \times W_L \times E_L \times (1 - F_{AV}).$$

## 3. Analysis of the electricity production of repowered WFs

The mechanical power, $P_{wind}$, represents the kinetic energy of the wind going through the rotor of a WTG, which depends on the non-disturbed wind speed ($v$), the air density ($\rho$) and the area swept by the rotor ($S$) according to the following expression:

$$P_{wind} = \tfrac{1}{2}\rho S v^3 \tag{1}$$

A WTG is able to extract only a portion of this kinetic energy to transform it into electricity. The limit of this transformation is $(16/27)\% \approx 59.25\%$, which is calculated according to Betz's law [36].

The formula for the mechanical power extractable from the wind stream by a WTG is

$$P_{util} = C_p \times P_{wind} = C_p \tfrac{1}{2}\rho S v^3 \tag{2}$$

where $C_p$ is the coefficient of performance and determines how efficiently the WTG takes advantage of the wind stream going through the rotor. The value of $C_p$ varies according to the wind speed and depends on the characteristics of the blades.

In addition, the increase of the wind speed with the height must be taken into consideration [37]. This increase depends on the particularities of the site. With the appropriate wind measurement campaign, the choice of the most convenient hub height can be determined.

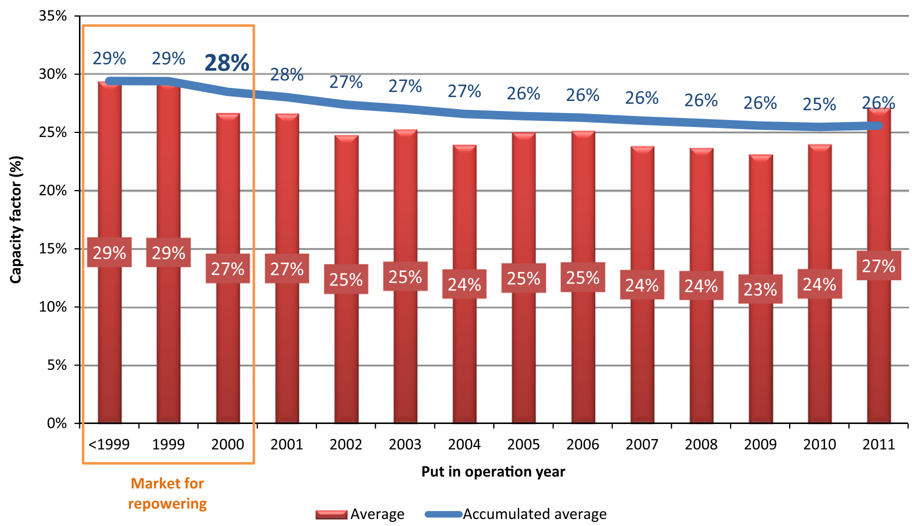


**Fig. 5.** Net average CF of WF's in the period 1998–2012 deployed for the year of entry in operation.
*Source*: CNE [12]

**Table 1**
Market volume and characteristics.

| Year placed in operation | < 2000 |
|---|---|
| Total installed power | 2.3 GW |
| WTG average size | 559–651 kW |
| WF average power size | 18 MW |
| Average net CF | 28% |

Therefore, on the basis of (2), the possibilities for an improved use of wind resources in a specified location are the following:

(1) Increase the diameter of the rotor by increasing the length of the blades.
(2) Increase the wind speed through the rotor by installing the WTG hub higher – with a higher tower.

Increase $C_p$ by installing the WTG with more efficient rotors.

In fact, the repowering of a WF takes advantage of these three possibilities when the older WTGs are replaced by those that are more technologically advanced and efficient, with larger blades and higher towers. In addition, new WTGs will have a larger rated power, making it possible to install more power in the best positions, i.e., those with more wind speed.

To quantify the effect of the replacement of a WTG, we performed a simulation of the expected production from wind measurements obtained over the last three years from an actual site located in the province of Lugo (Spain). As shown in Fig. 6, there are many other sites in the Spanish territory with similar wind conditions in terms of the average speed, so that the analysis performed in this section is valid for all of these sites.

The data were collected using a meteorological mast equipped with anemometers and wind vanes at heights of 45, 60 and 90 m and also equipped with pressure and temperature sensors. In addition, the mast provides a system to log, store and upload the raw data.

To characterize the wind resources in the site, the raw data were filtered and processed statistically. The characterization was performed using a probability Weibull distribution. The results, for the wind speed at heights of 45 m and 90 m are shown in Fig. 7.

The results classify the site in class I at a height of 90 m and in class II at a height of 45 m according to the classification established in IEC 61400-1 [24].

Two different types of WTGs were considered in the simulation:

(1) A representation of a WTG currently installed in a WF suitable for repowering and valid for the analyzed site (class II). As shown in Table 1, the rated power for a single unit is between 559 and 651 kW. In this range of power, the manufactures with more units installed (Vestas, Neg-Micon, Ecotecnia, Gamesa, and Made) had WTGs with 660 and 750 kW of rated power per unit [35], which were included in the representation. The hub height considered for these WTGs was 45 m, typical for the range of power.
(2) A representation of the WTGs currently offered by manufacturers and suitable for the analyzed site (class I). The rated power is between 2 and 3 MW because these are more frequently used [23], and among the possible hub heights, 90 m was chosen because we have actual measurements at that height.

Table 2 shows the main data and characteristics of the WTG used in the simulation.

Fig. 8 shows the power curves[7] of the WTGs included in the simulation as well as the Weibull distribution functions obtained for the analyzed site (shown in Fig. 7). It can be observed how the most modern WTGs exhibit a higher rated power and how they are able to more efficiently take advantage of the wind resource at low wind speeds between 5 and 10 m/s (lower than the speed at which nominal power is reached), which correspond to the more frequent range measured at the site.

The simulation to calculate the expected energy production was performed for each one of the WTGs using the software Windographer [42] considering one isolated WTG without including the weak losses [43].

The results of the simulation are shown in Fig. 9, where a large increase in the expected energy production given by the repowering or replacement of the old WTGs for the new ones is observed. Considering the average net CF obtained in the simulations for the WTGs that are representative of those currently installed (25.2% for NM48, 25.4% for AE46 and 29.1% for V47) over the average net CF for the new ones (45.3% for ECO100, 42.2% for G80 and 37.5% for

[7] The WTG power curve relates the speed of the wind running into the rotor with the power generated by the WTG. Usually, the power curve is verified and certified by an independent organization and is typically guaranteed by the WTG manufacturers, at least during the warranty period.

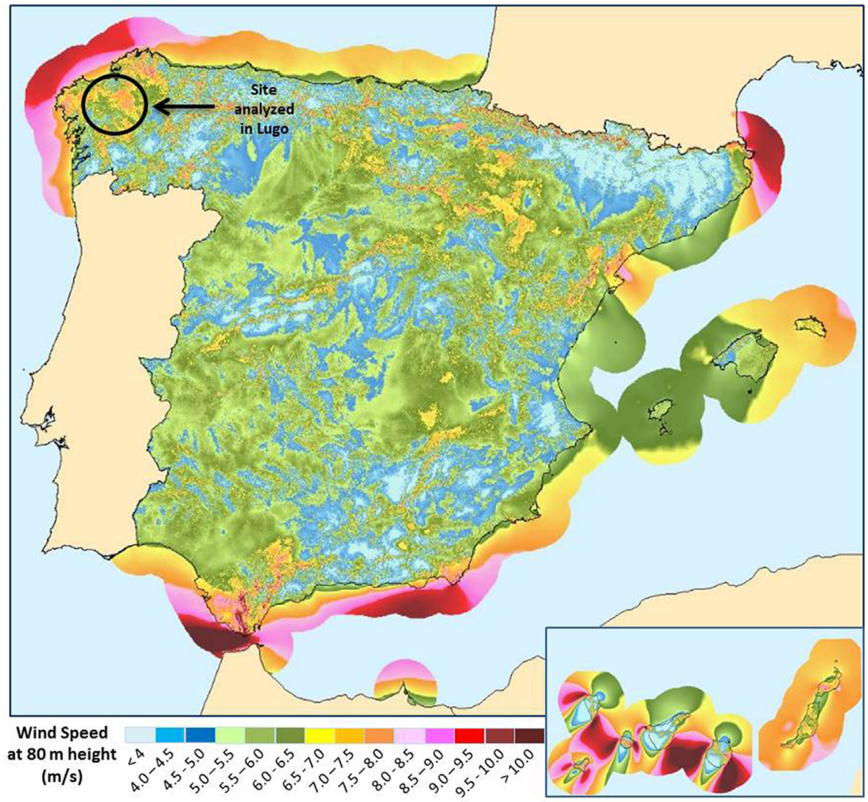


**Fig. 6.** Spanish wind map. Yearly average wind speed at 80-m height.
*Source*: IDAE [38]

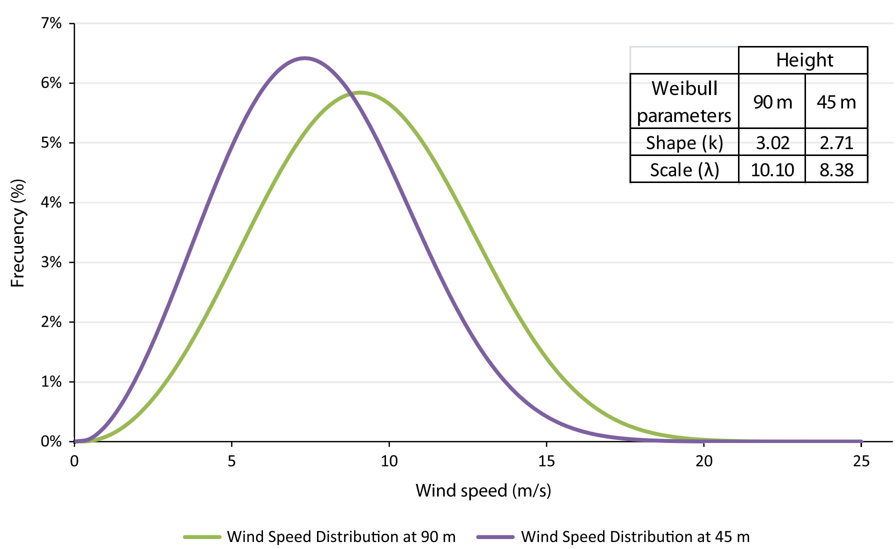


**Fig. 7.** Weibull curves and parameters for the wind speed distribution in the site.

**Table 2**
Characteristics of the WTGs included in the simulation.

| Manufacturer | Type | Nameplate power | Class according IEC 61400-12 | Rotor diameter (m) | Hub height (m) |
|---|---|---|---|---|---|
| MADE[a] [39] | AE-46 | 660 kW | II | 46 | 45 |
| NEG MICON[b] [40] | NM-48 | 750 kW | II | 48 | 45 |
| VESTAS [40] | V47 | 660 kW | II | 47 | 45 |
| ALSTOM [41] | ECO 100 | 3 MW | I | 100 | 90 |
| VESTAS | V90 | 3 MW | I | 90 | 90 |
| GAMESA [39] | G 80 | 2 MW | I | 80 | 90 |

[a] The MADE Company was merged with Gamesa in 1999.
[b] The Neg Micon Company was merged with Vestas in 2004.

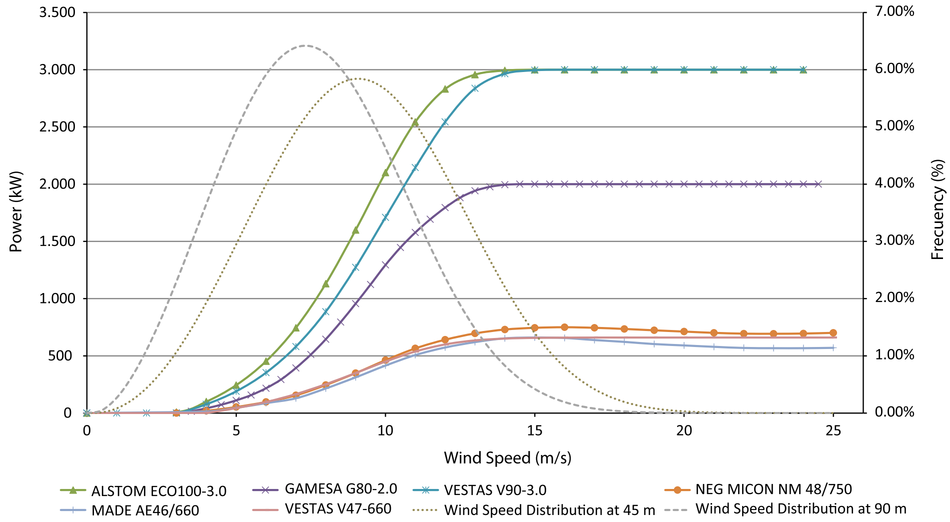


**Fig. 8.** Power curves of the WTG included in the simulation.

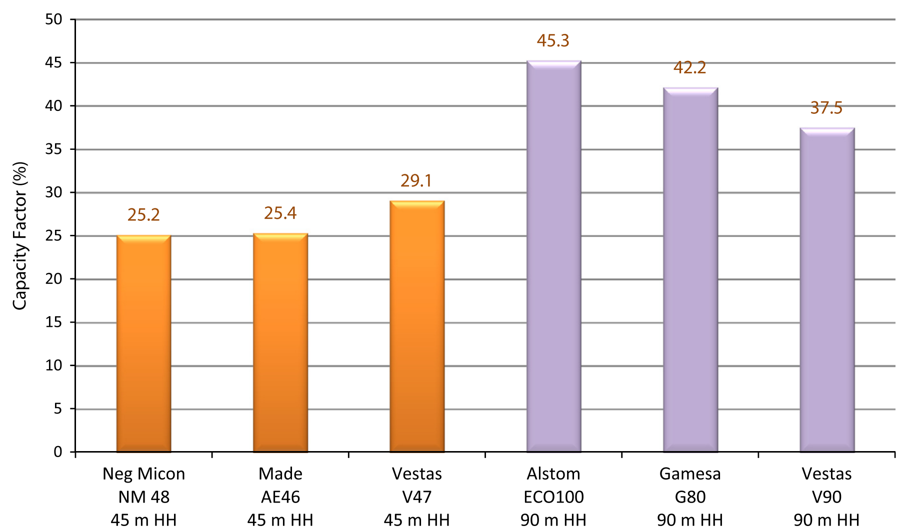


**Fig. 9.** CF estimated for the WTGs included in the simulation.

V90), the estimated increase of the net CF is approximately 57%. Moreover, in the best case scenario, the substitution of a Neg Micon NM48 (net CF of 25.2%) with an Alstom ECO100 (net CF of 45.3%) leads to an increase in the expected energy production with a net CF reaching a value of 79.8%.

Applying these results, the increase in the net CF was determined to be close to the previously obtained average value of 57%. Therefore, taking into consideration the characterization of a WF suitable for repowering that establishes the net CF of approximately 28% (see Table 1) in the remaining calculations, the average and representative value for the net CF for a Rep-WF was estimated to be 40% (a value lower than the result obtained from applying the 57% increase to the 28% characterization result; $28\% \times 1.57 = 43.96\% > 40\%$).

## 4. Definition of the scope of the works and the analysis of associated costs

The objective at this stage of the study was to define in detail the work required to develop, construct and operate a WF, estimate its cost according to the current market prices and differentiate the scope of works in two different cases: for a new WF (N-WF hereinafter) and for a Rep-WF. This study enables us to perform a comparative analysis of the feasibility for each case.

The scope of work for the development, construction and operation of a WF and its associated costs are different for a N-WF than for a Rep-WF. Among others factors, it is important to take into account that for a Rep-WF, some of the existing facilities can be reused and that before the repowering, it will be necessary to dismantle the old WTG.

The utilization of WTGs with higher unit power may enable an increase in the power of the WF after repowering. For an example, we have considered a distance between WTGs, measured perpendicular to the predominant wind direction, of three times the diameter of the rotor (a typical value for the design to reduce wake losses [44]). With this assumption, for WTGs with 46 m of rotor diameter and 660 kW of unit power, it is possible to install up to 2.4 MW/km, while for WTGs with 90 m of rotor diameter and 3 MW of unit power, it is possible to install up to 5.5 MW/km.

However, in the repowering process, it is very important to make an effort to maintain the validity and applicability of the permits, licenses and authorizations already obtained for the old WF. This will avoid additional work (and their associated costs) that could extend the development process.

This issue has a special relevance in relation to installed power because its variation can substantially modify the affected area of

**Table 3**
Comparison of capital and O&M costs between several sources and the estimate considered in the simulations.

| Source | Range | WTG cost[a] (€/kW) | WF cost (€/kW) | WTG O&M cost (€/kWh) |
|---|---|---|---|---|
| [45] **(Valid for 2010)** | min | | 1501 | 0.011 |
| | typ | 1176 | | |
| | max | | 1704 | 0.020 |
| [46] **(Valid for 2012)** | min | 752 | | |
| | typ | | 1592 | |
| | max | 1069 | | |
| [47] **(Valid for 2014)** | min | 560 | 800 | |
| | typ | | | |
| | max | 770 | 1100 | |
| [7,8] **(Valid for 2010)** | min | 744 | 1000 | 0.090 |
| | typ | | | |
| | max | 992 | 1300 | 0.120 |
| **Calculation based in the survey carried out for this paper. See Appendix A** | typ for a Rep-WF | 850 | 983 | 0.004 |
| | Typ for a N-WF | | 1108 | 0.006 |

[a] When the data source was in USD, data were converted to € using the following USD/€ exchange rates: 1.233 in 2010 (value in 2010/06/15), 1.263 in 2012 (value in 2012/06/15) and (1.349 in 2014) (value in 2014/02/10).

the WF and the permits and contracts subscribed for access to the electric grid. The little good in terms of RES integration is the installed power. In the process of sectorial regulation, as well as to fix domestic targets established in the development plans [8], the installed power was largely used to delimit the integration limits. In addition, an increase in WF power will involve important modifications in evacuation facilities (substations and line) with the associated costs.

In contrast, unless there were physical constraints in the site that could limit the installation of the required number of new WTGs to achieve the old WF capacity, it is convenient not to reduce it, thus maximizing the use of the affected area and the potential of the site.

Therefore, for the aim of this paper, the installed power in a Rep-WF was considered to not vary with respect to the authorized power for the old WF.

### 4.1. Capital costs

The capital costs vary widely depending on multiple factors. Among others, the following factors can be pointed as the most important: the market status (supply and demand), the site (country and local characteristics), the characteristics of the connection point to the electric grid, the existence of nearby WTG factories and the local presence of experienced sub-contractors.

With the aim of counting on a solid base for the calculation of the capital costs and considering the possible variations we did the following:

A survey among several international companies with a large experience in the Spanish market, including engineering, WTG manufacturers, civil works and electric infrastructure subcontractors. The detailed definition of the scope of works included in the survey and the prices obtained can be found in the Appendix A.

Include sensitivity analysis for the results in relation with the main capital cost corresponding with the WTG.

Table 3 shows a comparative for the main costs between several sources and the result of the survey we carried out for this paper applied to the characteristics for both the Rep-WF and the N-WF. As shown, the results are consistent with the other sources but with a focus in the market.

**Table 4**
Summary of the development costs.
*Source*: Self-elaboration based on Table A1

| Item | New WF | | | Rep-WF | | |
|---|---|---|---|---|---|---|
| | €/kW | € | % | €/kW | € | % |
| ***Engineering*** | ***2.2*** | ***40,000*** | ***12%*** | ***2.2*** | ***40,000*** | ***15%*** |
| ***Wind resource assessment*** | ***4.8*** | ***87,000*** | ***25%*** | ***0.4*** | ***7000*** | ***3%*** |
| Meteo tower rent | 4.4 | 80,000 | | 0.0 | 0 | |
| Final report | 0.4 | 7000 | | 0.4 | 7,000 | |
| ***Personnel*** | ***12.2*** | ***220,000*** | ***63%*** | ***12.2*** | ***220,000*** | ***82%*** |
| Hourly average cost | 6.7 | 120,000 | | 6.7 | 120,000 | |
| Other personnel costs | 5.6 | 100,000 | | 5.6 | 100,000 | |
| **Total development costs** | **19.3** | **347,000** | **100%** | **14.8** | **267,000** | **100%** |

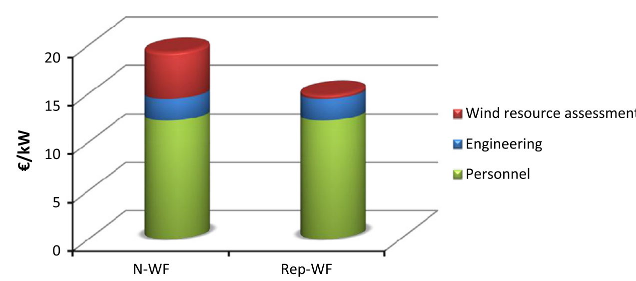


**Fig. 10.** Deployment of the development costs per kW.

#### 4.1.1. Development

Development is performed prior to the construction of the WF and consist mainly of the study of the wind resource, the technical definition of the project and the management of the permits, licenses and authorizations necessary for the construction and the commercial operation.

Table 4 and Fig. 10 present a summary of the development costs to take into consideration in a N-WF or in the repowering of an existing one. The only difference is the wind resource assessment required to make an appropriate choice for the new WTG as well as a good production estimate. In the case of a Rep-WF, it will not be necessary to perform a new measurement campaign of wind resources because the data were obtained during the commercial operational period of the old WF.

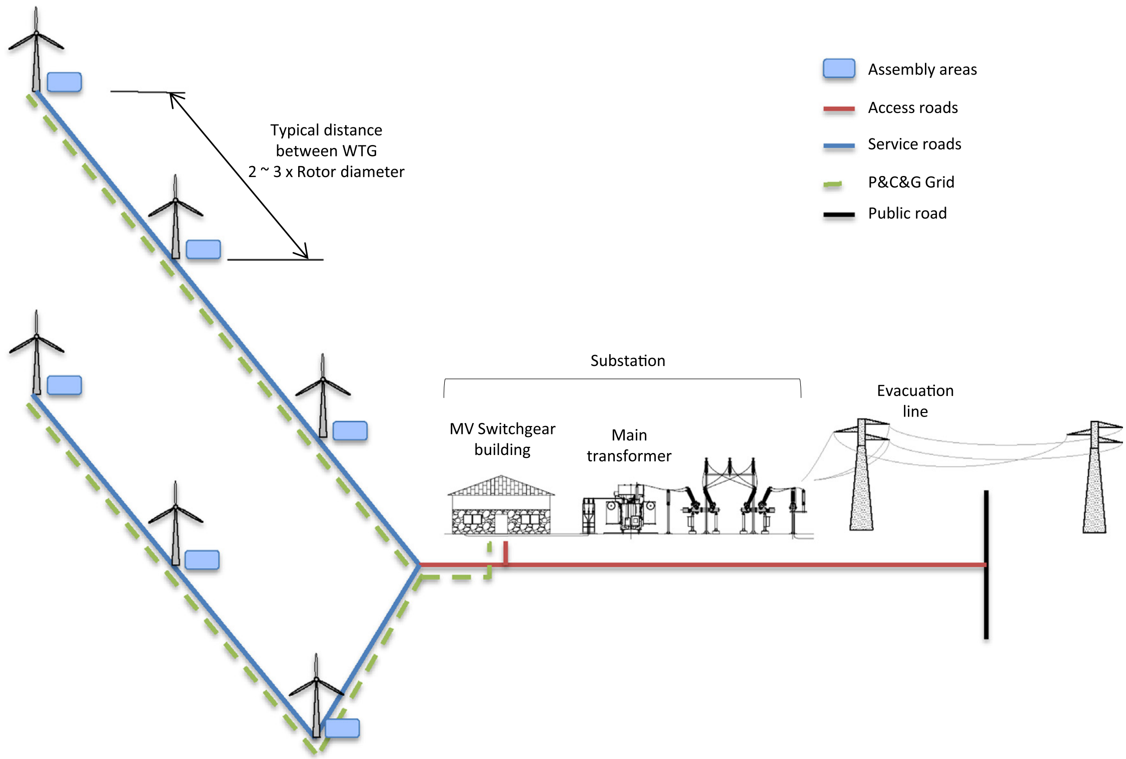


**Fig. 11.** Facilities in a WF.

**Table 5**
Summary of the construction costs.
*Source*: Self-elaboration based on Table A2

| Item | New WF | | | Rep WF | | |
|---|---|---|---|---|---|---|
| | €/kW | € | % | €/kW | € | % |
| ***Main equipment*** | ***853.9*** | ***15,370,000*** | ***78*** | ***853.9*** | ***15,370,000*** | ***88*** |
| WTG | 850.0 | 15,300,000 | | 850.0 | 15,300,000 | |
| Meteorological mast | 3.9 | 70,000 | | 3.9 | 70,000 | |
| ***Foundations and assembly areas*** | ***56.1*** | ***1,010,000*** | ***5*** | ***56.1*** | ***1,010,000*** | ***6*** |
| Foundations | 53.3 | 960,000 | | 53.3 | 960,000 | |
| Assembly areas | 2.8 | 50,000 | | 2.8 | 50,000 | |
| ***Roads*** | ***26.0*** | ***468,000*** | ***2*** | ***17.3*** | ***312,000*** | ***2*** |
| Access road length | 12.5 | 225,000 | | 8.3 | 150,000 | |
| Services road length | 13.5 | 243,000 | | 9.0 | 162,000 | |
| ***P&C&G grid*** | ***15.3*** | ***275,400*** | ***1*** | ***15.3*** | ***275,400*** | ***2*** |
| Civil works | 11.3 | 202,500 | | 11.3 | 202,500 | |
| Supply and installation | 4.1 | 72,900 | | 4.1 | 72,900 | |
| ***Substation*** | ***55.6*** | ***1,000,000*** | ***5*** | ***0.0*** | ***0*** | ***0*** |
| High voltage level | 30.6 | 550,000 | | 0.0 | 0 | |
| Medium voltage level | 8.3 | 150,000 | | 0.0 | 0 | |
| Main transformer power | 16.7 | 300,000 | | 0.0 | 0 | |
| ***Evacuation line*** | ***34.7*** | ***625,000*** | ***3*** | ***0.0*** | ***0*** | ***0*** |
| ***Construction Permits*** | ***47.2*** | ***849,957*** | ***4*** | ***25.9*** | ***466,825*** | ***3*** |
| County Construction license | 2.2 | 40,110 | | 1.7 | 30,490 | |
| Urban license | 26.0 | 468,710 | | 23.6 | 424,185 | |
| Land owners permits | 19.0 | 341,137 | | 0.7 | 12,150 | |
| **Total construction costs** | **1088.8** | **19,598,357** | **100** | **968.6** | **17,434,225** | **100** |

*4.1.2. Construction*

For a given WTG, the facilities of a WF will depend on its geographical location (distance to the public road network, soil characteristics, rainfall, etc.) and the way to connect it to the electric grid (voltage level, evacuation line, specifications for the connection point, etc.). However, several basic elements allow us to estimate the costs of construction with an appropriate accuracy for the objectives of this paper.

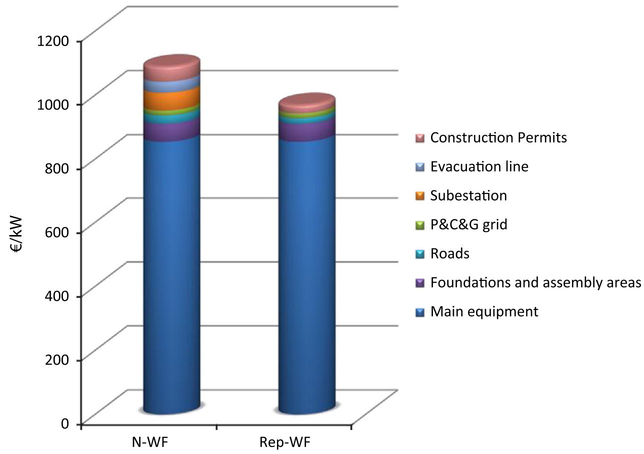


**Fig. 12.** Deployment of the construction costs per kW.

A basic scheme of the facilities, which is considered for the definition of the scope of the construction and the estimation of their associated costs, is shown in Fig. 11. These facilities are as follows:

The foundations of the WTG and the assembly areas to support the cranes and heavy transport vehicles during the assembly and maintenance of the WF.
The roads to allow access to all the facilities from the public transport network. These roads should be suitable for the transit of large-dimension transport vehicles and cranes.
The power, communications and grounding grid (P&C&G grid hereinafter). The P&C&G is composed of high-voltage cables and accessories to take the power generated in each WTG to the substation, communications cables (usually optical fiber) to provide communications between the WTGs, a meteorological tower, a supervisory control and data acquisition system (SCADA hereinafter) and ground network cables (usually bare copper wire). The associated civil works are also included.
The electric substation, in which the electricity generated by the WTG is collected, typically at a voltage level between 15 and 33 kV, and transformed to the voltage level of the electric grid where the WF connects.
The evacuation line to carry the electricity from the substation up to the connection point with the electric grid.

The extent of the roads and the P&C&G grid is directly conditioned by the distance between the WTGs. Obviously, the best positions, in terms of wind resource, should be selected. With the objective to maximize generation with the minimum cost, several methods have been suggested to optimize WF layouts [48], however, very often, especially in sites where wind resources are homogenous over all the area available and for the purpose of minimizing losses caused by the wake effect [43] the WTGs should be located with a distance in the range of two or three times the length of the WTG rotor diameter in the line perpendicular to the prevailing wind direction. At the same time, the typical distance between two WTG lines – both perpendicular to the prevailing wind direction – is approximately 10 times the length of the WTG rotor diameter [44].

Table 5 and Fig. 12 detail the construction costs considered for a N-WF and for a Rep-WF. As one might expect, the construction of a Rep-WF is less expensive for the following reasons:

(1) The roads must be constructed for a N-WF, while they only require renovation and adaption to the requirements of the new WTGs (dimensions and weights) for a Rep-WF.
(2) According to the assumption previously mentioned in this section, the installed power will not change; therefore, there is no work required in the substation and the evacuation line for a Rep-WF.
(3) The cost of the permits, which is calculated over the construction costs, will be higher for a N-WF.
(4) For a Rep-WF, the only land permits required are for new roads and P&C&G grid facilities.

**Table 6**
Dismantling and waste disposal costs and valorization incomes.
*Source*: Self-elaboration. Prices for dismantling and waste disposal are based on offers received in 2013 from companies that are specialized in the assembly and transportation of WTGs.

| Item | €/kW | € |
|---|---|---|
| *Dismantling of WTG's and waste disposal* | *67.5* | *1,215,000* |
| *Valorization of valuable scrap materials* | *−25.9* | *−465,973* |
| **Net effect** | **41.6** | **749,027** |

**Table 7**
Deployment and prices for valuable waste.
*Source*: Self-elaboration. Steel and copper mass per WTG from manufacturers information.Prices for valuable waste from [51,52]

| Item | Average valuable waste per WTG | |
|---|---|---|
| | Steel (kg) | Copper (kg) |
| Blades (3#) | 698 | |
| Hub | 2320 | |
| Anchorage | 3000 | |
| Tower | 30,000 | |
| Main frame | 6000 | |
| Shaft (including bearing) | 3100 | |
| Gearbox | 8000 | |
| Coupling | 160 | Irrelevant |
| Yaw gear motor | 500 | Irrelevant |
| Yaw ring | 620 | |
| Hydraulic unit | 60 | |
| Generator | | 1000 |
| Cables | | 866 |
| **Quantity per WTG** | **54,458** | **1866** |
| Unitary price (€/kg) | 0.280 | 1.077 |
| **Total price (€/WTG)** | **15,248** | **2010** |

### 4.2. Dismantling works and valorization of the valuable waste

For a market that is able to install more than 22 GW, the dismantling of an old WTG, which are much lighter and smaller than the new ones, is not a barrier for repowering. The services offered by specialized companies and the technical resources for the elevation and transport of heavy loads exceeds the necessities to perform these tasks.

The dismantling works and valorization of valuable waste will include

(1) The dismantling of the WTGs into manageable parts.
(2) Ensuring the adequacy of the transportation.
(3) The classification and transport of non-valuable waste and the delivery to authorized agents for their treatment.
(4) The transport of valuable waste to the delivery point.

For the dismantling and restoration of the rest of the facilities not reused in a Rep-WF the following assumptions have been taken into consideration:

*Foundations*: The dismantling is limited to eliminate protruding parts from the soil surface, usually consisting of the upper

anchorage or anchor bolts and the structural concrete. After that, the surface is levelled and refilled with appropriate material; finally, environmental restoration will be performed.

*Assembly areas*: Due to environmental requirements, the assembly areas were normally restored at the end of the construction of the old WF; thus, no dismantling work is required.

*Roads*: Restoration is not required because they will be largely reused, and for the parts that are not reused, their removal is not advised because they provide an important service to the community by facilitating access or acting as firebreaks.

P&C&G grid: Reuse is not feasible because the positions of the WTGs will not be the same. In addition, restoration is not necessary because common practice is to bury the cables deeply enough to allow others soil uses (e.g., agriculture) and, according to environmental requirements, trenches must be restored upon completion of the old WF.

The appropriate time for the completion of the aforementioned works of dismantling and restoration is during the construction of new facilities for a Rep-WF. In this case, the cost of all of these construction projects can be considered to be a residual value and should be included in the construction scope for the Rep-WF (Table 5)

Regarding waste management, there are two different cases, depending on whether the waste is valuable, i.e., whether it is possible to obtain income with their disposal for recycling.

In the case of non-valuable waste (oil, plastic, etc.), the waste items should have their origins classified and be moved directly to qualified organizations authorized for their treatment and recycling. The costs of these tasks are included in the dismantling costs listed in Table 6, which were obtained by means of a request for a proposal issued to 10 companies that are specialized in the assembly and transport of WTGs.

In the case of valuable waste, currently, there are stable markets in which these waste items can be traded, thereby obtaining economic incomes [49,50]. Among all the valuable waste found in a WTG, the most important because of their quantity and price are copper and steel. Table 7 details the amount of copper and steel waste and their origin from a WTG. The amounts indicated are the average value for the three class II WTGs included in Table 2, the individual values were obtained from manufacturer's technical information.

The net effect of the dismantling works and the management and valorization of waste, shown in Table 6, was considered in the costs associated with repowering.

### 4.3. Operation works

The operation works are those necessary to keep the WF that is in commercial operation in optimal technical and safety conditions.

Among the operation works, the most important and expensive corresponds with the WTG O&M. This task is normally provided by the manufacturer of the WTGs and usually includes a mechanical availability guarantee.

A request for an updated WTG O&M price was included in the survey carried out among WTG manufactures for this paper. The result is included in Table 8, as well as the scope and the unitary costs for the operation works. The operation works, and therefore, the associated costs, are equal in both cases, for a N-WF and for a Rep-WF because the number of WTGs installed and the balance of plant infrastructures will be the same.

## 5. Profitability analysis

The substitution of old WTGs will bring environmental benefits [55]. Repowering would also bring important benefits for the entire electricity system, which would be mainly derived from the improved use of energetic sources by means of more efficient WTGs.

According to [56] a reduction in the spot price is expected with the increase of wind energy integration in the Iberian market (Spain and Portugal), while [57] predicts a very small impact in household electricity prices in EU countries. Integration could be favored by repowering due to the change of the old WTGs for ones more adapted to the new technical regulations.

Nevertheless, in a liberalized market, as that which exists in Span, the main decision factor for a possible investor to participate in it is the expected profitability, which is assured by regulatory stability.

Currently, the retributive system based on a FIT is suspended both for new plants and for the repowering of WFs in commercial operations [13]. Thus, as the main objective of this study, it is necessary to search for alternatives to ensure sufficient incomes to make repowering projects profitable.

**Table 9**
Cash flow calculation method.

| | **Shareholder cash flow** |
|---|---|
| + | Incomes from electricity remuneration |
| − | Operating expenses |
| = | **Gross operating margin (EBITDA)** |
| − | Depreciation |
| = | **Earnings before interests and taxes (EBIT)** |
| − | Financial expenses |
| = | **Earnings before taxes** |
| − | Taxes |
| = | **Earnings after taxes** |
| + | Depreciation |
| = | **Yearly cash flow** ($CF_z$) |
| + | Cumulative previous year cash flow |
| = | **Cumulative present year cash flow** ($CFA_z$) |

**Table 8**
Operation works scope and unitary prices.
*Source*: Prices for O&M are based on offers received in 2013 from WTG manufacturers and companies that are specialized in the balance of plant O&M services.

| Item | Scope, prices and characteristics | | Comment |
|---|---|---|---|
| **O&M** | *WTG* | *50.000€/(WTG × year)* | |
| | *Balance of plant* | *125.000€/year* | Roads, substation and evacuation line |
| **Land easements** | *WTG* | *3.000€/(MW × year)* | Including assembly areas |
| **Insurance and administration** | *Insurance* | *0.50% Incomes* | All risk and Civil Liability. Typically calculated over incomes |
| | *Administration* | *0.15* | Typically calculated over incomes |
| **Cost update** | *Annual increase of operation costs* | *2* | Estimate based on the trend in the inflation forecast [53,54] |

**Table 10**
Common assumptions in IRR calculation for both scenarios.

| Item | Name | Value | Unit | Comment |
|---|---|---|---|---|
| **General** | WF power | 18 | MW | According to Table 1 |
| | Number of WTG | 6 | | Corresponding with 3 MW nameplate power WTG |
| | Commercial operation year | 2015 | | One year of construction period starting in 2014 |
| **Tariff** | Average spot price 2013 | 50.49 | €/MWh | Average price from 2013. Source: OMIE [60] |
| | Annual increase of spot price | 2 | % | Typically indexed to inflation. Estimate based on the trend in the inflation forecast [53,54] |
| **Electricity generation and losses** | Wake losses ($W_L$) | 5 | % | Typical |
| | Electric losses ($E_L$) | 3 | % | Estimate. It includes from WTG transformers up to grid connection point |
| | WTG mechanical availability ($F_{AV}$) | 95 | % | Current market value. Source: WTG Manufacturers |
| **Taxes** | Profit taxes | 30 | % | |
| | Income taxes | 2 | % | The final value depends on council and incomes level. Mean value has been taken into consideration |
| | VAT | 21 | % | |
| **Financial terms** | Financial leverage (FL) | 70 | % | Over total costs. Estimate from [61] |
| | Interest rate | 5 | % | Annual estimate from [61] |
| | Loan repayment period | 10 | years | Typical |
| | $T_{DEP}$ | 10 | years | Typical |

From an economic point of view, the most favorable solution for the entire electric system would be to pay the spot price for the electricity generated by a WF, being able to provide energy in terms of grid parity. This model is currently being successfully applied in countries with emergent economies (e.g., Chile) even to support projects based in photovoltaic and concentrated solar thermal technologies, which are less efficient than wind energy [58,59].

The retributive system proposed and analyzed in this study is based on the following assumptions:

(1) Maintain the right to export the entire electricity surplus to the electric grid when it is technically feasible.
(2) Participate in the daily electricity market and charge the hourly spot price for the electricity fed into grid.

Under these assumptions, the analysis focused in two aspects: first, if a Rep-WF can provide an interesting profitability opportunity for the investors, being a similar or even better choice than constructing a N-WF, and second, if the retributive proposal is sufficient to ensure profitability.

To achieve this objective, two scenarios were analyzed and compared:

(1) The repowering of an existing WF with the characteristics indicated in Table 1.
(2) The construction of a WF in a new site, taking into consideration the development, construction and operation costs calculated in Section 4. To obtain homogeneous results, the installed power considered in this case has been the same as that considered in scenario 1 but the results are applicable to WFs in the same range of installed power.[8]

In both scenarios, the profitability for the investor was estimated using the internal rate of return (IRR hereinafter) calculated for a period equal to the WTG lifetime – 20 years – considering an external financing source. This return is known as the Shareholder IRR.

Before obtaining the IRR, the cash flows of the investment are calculated following the method described in Table 9.

The net present value (NPV, hereafter) of the investment is calculated from each of the yearly cash flows, discounting back to its present value at the discount rate k, that is

$$\mathrm{NPV} = \sum_{z=1}^{n} \frac{CF_z}{(1+k)^z} - I_o \tag{3}$$

where $I_o$ is the portion of the total cost assumed by the investor, with its value depending on the Financial Leverage (FL hereinafter)[9]:

$$I_o = \mathrm{FL} \times \text{Total Cost} = \mathrm{FL} \times (\text{Development cost} + \text{Construction cost}) \tag{4}$$

IRR is defined as the interest rate k at which the NPV is zero, that is

$$0 = \sum_{z=1}^{n} \frac{CF_z}{(1+\mathrm{IRR})^z} - I_o \tag{5}$$

The common assumptions in the IRR calculations for both scenarios are detailed in Table 10.

The particular assumptions in the IRR calculations for each scenario are detailed and distinguished in Table 11.

Fig. 13 shows the variation of IRR as a function of CF in both scenarios analyzed. It can be observed that

(1) The IRR for a Rep-WF is independent of the CF and higher than the IRR for a N-WF because the total costs for the development and construction are lower, mainly due to the reuse of the electric infrastructure – substation and evacuation line.
(2) The IRR for a Rep-WF, with the increase of the CF after the repowering calculated in Section 3 (approximately 46% of the gross value or 40% of the net value), is greater than the IRR for a N-WF with the current expected value of CF (approximately 31% of the gross value or 27% of the net value).
(3) The IRR for a Rep-WF, with the increase of the CF and charging the spot price for the electricity generated, is even better than the IRR for the construction of a N-WF with the current expected value of CF (approximately 31% of the gross value or 27% of the net value).

[8] According with the Spanish regulation there is a limit for the installed power of RES facilities. For WFs this limit is of 50 MW.

[9] The financial leverage (FL) is the percentage of the investment financed with an external resource or debt.

**Table 11**
Particular assumptions in IRR calculations.

| Item | Name | New WF | | Rep WF | | Comment |
|---|---|---|---|---|---|---|
| | | Value | Unit | Value | Unit | |
| **Costs** | Development – total | 19.28 | €/kW | 14.83 | €/kW | According to calculations in Section 4 |
| | Construction – total | 1088.80 | €/kW | 968.57 | €/kW | |
| | Dismantling and valorizations – net effect | 0.00 | €/kW | 41.61 | €/kW | |
| **Electricity generation and losses** | Gross CF | 31 | % | 46 | % | According to Section 3 |
| | Net CF | 27 | % | 40 | % | |

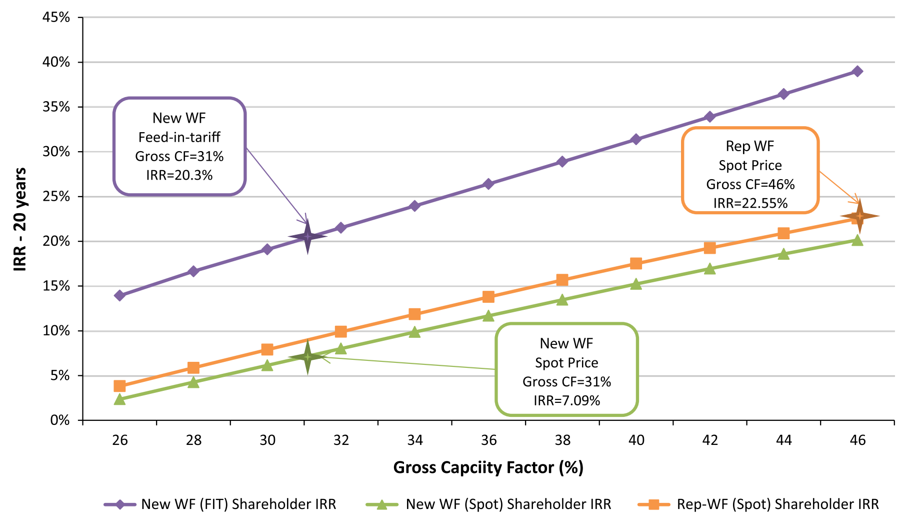


**Fig. 13.** IRR as a function of the gross CF.

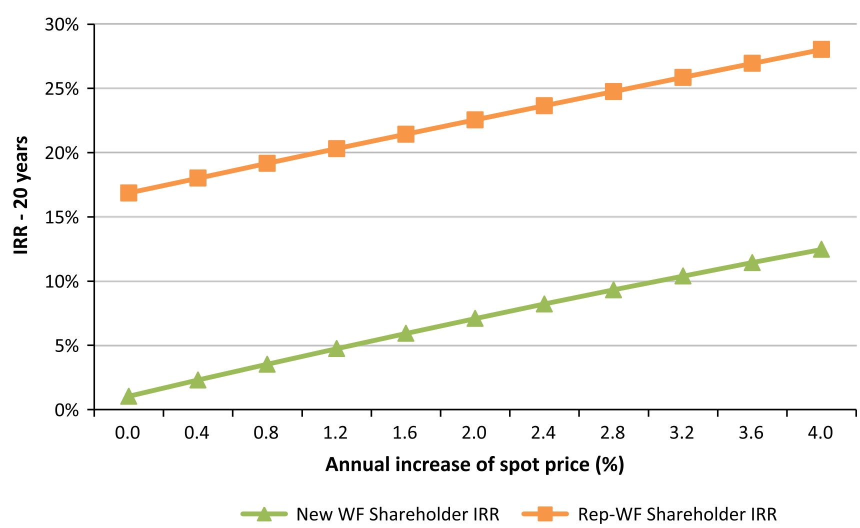


**Fig. 14.** IRR as a function of the annual increase of the spot price.

## 5.1. *Sensitivity of the IRR results*

### 5.1.1. *Sensitivity in relation to incomes*

Naturally, the variation of incomes has an important impact on the expected profitability because they are produced recurrently during the entire WF lifetime and provide the support to repay the debt. The path of growth estimated in the IRR calculations for the spot price, and thus for incomes, was 2% (annual increase of the spot price in Table 10 but the estimates made by the European Union exceed this value, foreseeing yearly increases of up to 15% [62]).

Fig. 14 shows the sensitivity of the expected IRR in relation to the variation of the trajectory of growth for the spot price. The sensitivity curve was obtained by varying the "Annual increase of spot price" value (Table 10) between 0% and 4%, keeping the rest of the assumptions fixed.

### 5.1.2. *Sensitivity in relation to the costs*

The WTG represents the most important cost in the construction of the WF, hence the sensitivity of the IRR in relation to the costs was focused in the variation of the WTG cost.

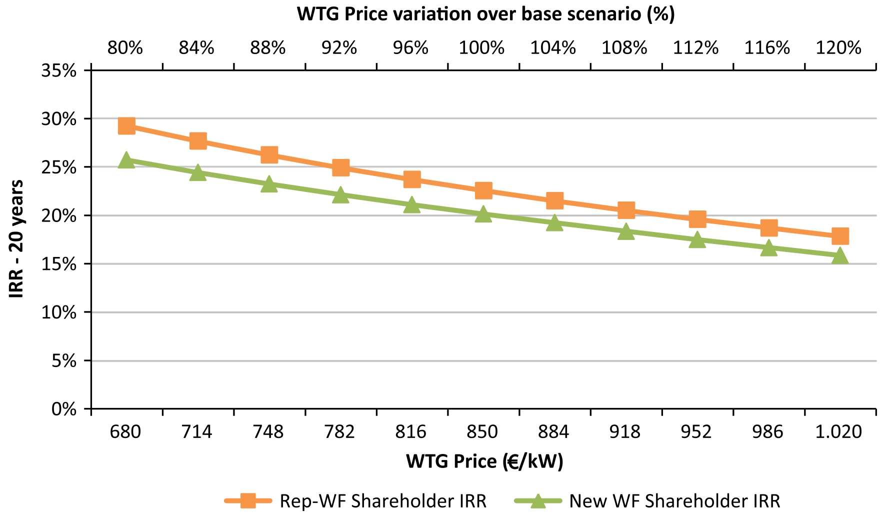


**Fig. 15.** IRR as a function of the WTG price.

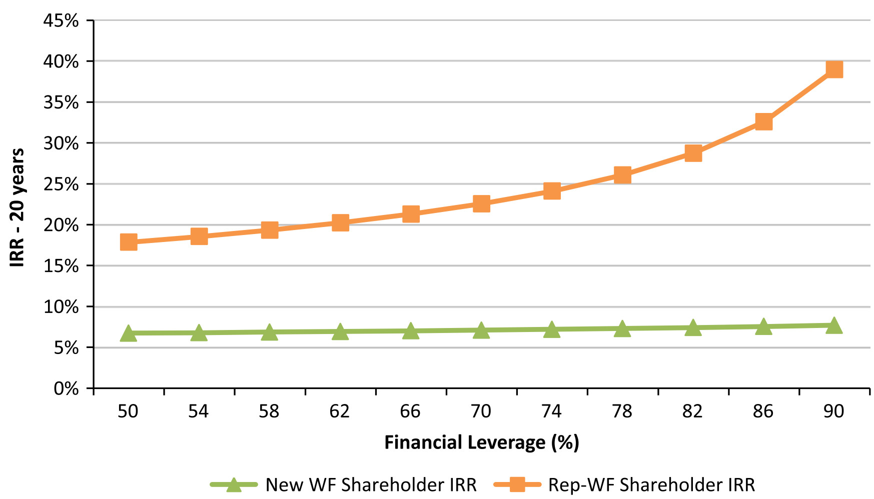


**Fig. 16.** IRR as a function of the FL for both scenarios.

Fig. 15 shows the IRR as a function of the WTG cost. The curve was obtained by varying the price for the WTG in the base scenario (Table A2) while keeping the other costs and assumptions fixed.

### *5.1.3. Sensitivity in relation to the FL*

A way to improve the Shareholder IRR consists of obtaining better conditions in the Project Finance. This solution would not result in extra costs for the electric system due to an increase of the price for the electricity generated by means of a FIT or bonus over the spot price. Among these conditions, the variation of FL has the greatest effect.

Fig. 16 shows the IRR as a function of the FL. The curve was obtained by varying the value for FL (Table 10) between 50% and 90% while keeping other assumptions fixed. A low sensitivity of the IRR for the N-WF was indicated because the IRR is too low in the base case and the variation of FL does not have a perceptible effect. However, for the Rep-WF, the figure indicates how important growth can be obtained by improving the financial conditions without increasing the price for the energy fed into the grid.

### *5.1.4. Sensitivity in relation to taxes*

Among the taxes applied to the activity of the generation of electricity during commercial operation, the most important, due to its value, is the profit tax.

Fig. 17 shows the IRR as a function of the profit tax that was obtained by varying its value (Table 10 over the range of 10% and 30% and keeping the rest of assumptions fixed). It can be observed that the sensitivity of the IRR is not significant in this case; therefore, the reduction of the tax burden will not have a relevant effect in the decision to go ahead with repowering.

## 6. Conclusions

In light of all that has been accomplished in this work, the investment in the repowering of a WF can be more profitable than investing in a N-WF if the new WTGs are properly selected according to the wind resources at the site and if the facilities for the extraction of the electricity generated are reused.

The total cost is lower for a Rep-WF, even when considering the costs for dismantling the older WTGs because these dismantling costs are considerably reduced by the incomes obtained from the valorization of the valuable waste.

For an old WF with wind resources greater than those recently made or than the sites currently available, the repowering with new WTGs, which are more efficient and technologically advanced, enables a better use of the wind. This fact allows a Rep-WF to sell the energy produced at the spot price, offering a

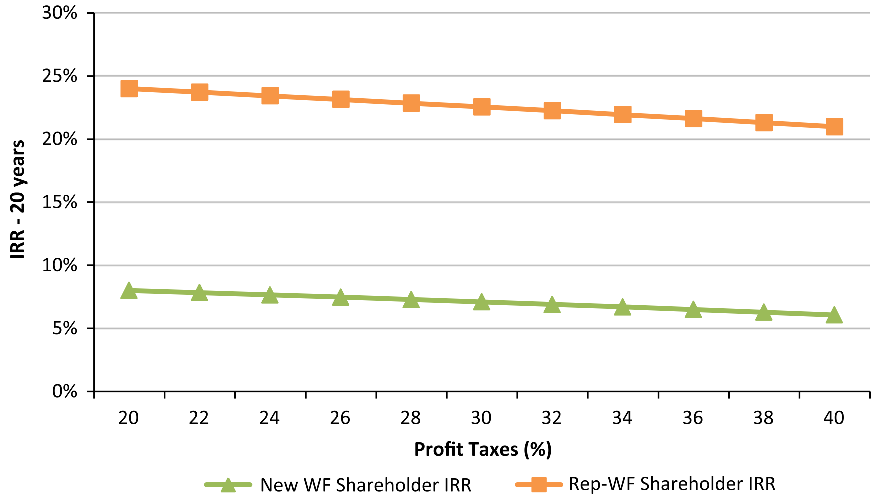


**Fig. 17.** IRR as a function of the profit taxes for both scenarios.

similar or even better profitability than a N-WF, with a CF that is much lower than that with a retributive system based on a FIT.

Currently, there is a market for repowering of approximately 2.3 GW of installed power in the entire Spanish territory with a period in commercial operation equal to or greater than 13 years. This volume will increase in the next few years – at a rate of approximately 1 GW per year – as electricity generation plants age.

Profitability is strongly subject to the electricity price; thus, the mid-term stability of the price or the possibility to forecast its evolution could make an important contribution in the decision to implement repowering. Nevertheless, there are solutions capable of providing security to investors: bilateral contracts for selling energy to consumers or traders and new products offered for insurance companies to ensure a minimum value in case the spot price decreases below the minimum value. These solutions are successfully being used in emerging markets to finance RES power plants.

Repowering requires a specific framework that is both technical and retributive, which should be taken into consideration in the next Spanish regulation implemented to allow participation in the daily market and to fit the characteristics of the technology. In addition, legal measurements can be established to improve profitability without an extra cost for the entire electric system by facilitating the access to financial credits for the investors. These measurements should be aimed at providing stability to the incomes and legal security in the long-term for the investment. In this way, investors will be more willing to commit funds to develop Rep-WF projects.

In summary, the repowering approach appears to be a real and feasible option for relaunching the integration of RESs into the Spanish energy mix. In the current situation, due to the lack of specific regulation, an adequate policy framework would enable the development of a large-sized market with sustainable growth in the short term. In addition, the electricity produced by Rep-WFs would be included in the electric market in the condition of grid parity, implying important savings for the entire system with respect to the retributive system based on a FIT applied to the WFs suitable for repowering to date.

## Acknowledgments

The authors especially thank the following people for their contributions: Mr. Sergio Robles (Indra), Mr. José Carlos Bustos (Gamesa), Mr. David Gómez de Lucas and Mr. José Carlos García Sánchez (Isolux Ingeniería), Mr. Claudio Cortina (Aguado Wind), Mr. José Luis del Cerro Rico (Vestas Mediterranean) and Mr. Josep-María Borrell (Alstom Wind).

## Appendix A. Detailed calculation of the development and construction costs

For the purposes of this paper, during the year 2013 a survey was carried out among several international companies specializing in the different procedures necessary for the construction and operation of a WF.

To make the estimations, technical requirements and bills of quantities were delivered to all the requested companies. All of this documentation was performed considering the WF characteristics determined by simulations (Table 1) and the scope of works established in Section 4.

The results of the survey for development and construction costs are included in the following tables for a WF of 20 MW. Nevertheless, the figures are applicable to WFs in the same installed power range.

Table A1 details the scope of the development and their associated costs.

Table A2 shows in detail the scope of the construction and the average costs associated.

**Table A1**
Development scope and unitary prices.
*Source*: Self-elaboration based on the survey carried out among specialized companies in engineering and wind resource measurement and assessment. Prices valid for H2 2013

| Item | Scope, prices and characteristics | | | Comment |
|---|---|---|---|---|
| **Engineering** | *Technical project* | | *30,000€* | The price includes the definition of the installations (WTG lay-out, power, communication and grounding grid, substation, evacuation line) and the technical specifications, drawings and supplements for informing the institutions and the other services affected. |
| | *Environmental report* | | *10,000€* | |
| **Wind resource assessment** | *Meteo tower rent* | | *40,000 €/year* | Includes the logger and the calibrated sensors. |
| | Height | 90 m | | |
| | Measurement heights | 60/75/90 m | | Includes periodic downloads of the raw data. |
| | *Final report* | | *7000€* | |
| **Personnel** | *Hourly average cost* | | *200€/h* | |
| | Hours of labor | 600 h | | |
| | *Other personnel costs* | | *100,000 €* | Travel, etc. |

**Table A2**
Construction scope and unitary prices.
*Source*: Self-elaboration based on the survey carried out with WTG manufacturers, electric materials suppliers, civil works and electric contractors and specialized companies for permits management. Prices valid for H2 2013

| Item | Scope, prices and characteristics | | | Comment |
|---|---|---|---|---|
| **WTG** | *WTG* | | *850* | The price includes: |
| | WTG unitary power | 3 MW | | Assembly and commissioning |
| | Number of WTGs | 6 units | | SCADA |
| | Hub height (HH) | 90 m | | Systems for controlling reactive power and generation |
| | Rotor diameter | 90 m | | |
| **Meteorological mast** | *Meteo mast* | | *70,000* | Includes logger and calibrated sensors |
| | Height | 90 m | | |
| | Measurement heights | 60/75/90 m | | |
| **Foundations and assembly areas** | *Foundation* | | *160,000* | Structural concrete: 430 $m^3$ |
| | Foundation dimensions | $15 \times 15 \times 2\ m^3$ | | Steel bars: 25 t |
| | *Assembly area* | | *25* | Includes clearance, excavation, levelling and refilling with the appropriate material |
| | Dimensions | $40 \times 50\ m^2$ | | |
| **Roads** | *Construction of new roads* | | *150* | Includes clearance, excavation, levelling and refilling with the appropriate material |
| | Average distance between WTG (three times rotor diameter) | 270 m | | |
| | Access road length | 1500 m | | Includes storm water trenches |
| | Services road length | 1620 m | | |
| | *Adaptation of existing roads* | | *100* | |
| **P&C&G grid** | *Civil works* | | *100* | Includes excavation, signalisation and refilling with the appropriate material |
| | Trenches length | 2025 m | | |
| | *MV power cables* | | *15€/m* | Includes terminations, junctions and connections |
| | Maximum current per sub-circuit | 630 A | | |
| | Circuits number | 2 | | |
| | Length | 2430 | | |
| | *Optical fiber cables* | | *6€/m* | Includes terminations, junctions and connections |
| | Type | Single-mode | | |
| | Length | 2025 m | | |
| | *Grounding cables* | | *12€/m* | Includes terminations, junctions and connections |
| | Section | 50 m | | |
| | Length | 2025 m | | |
| **Substation** | *High voltage EPC price* | | *550,000 €* | The price includes an outdoor bay for line and transformer protection fully equipped and a control building |
| | High voltage level | 132 kV | | |
| | *Medium voltage EPC price* | | *150,000 €* | Includes the following MV switchgears: bars measurement, transformer protection, line from WTG protection and auxiliary services transformer protection |
| | Medium voltage level | 33 kV | | |
| | *Transformer price* | | *300,000 €* | ONAN/OFAF refrigeration |
| | Main transformer power | 20 MVA | | Equipped with on-load tap changer |
| **Evacuation line** | *EPC price* | | *125,000 €/km* | Overhead line single circuit |
| | Voltage level | 132 kV | | Includes a fiber optic cable for communications installed in the earth |

**Table A2** (*continued*)

| Item | Scope, prices and characteristics | | | Comment |
|---|---|---|---|---|
| | Length | 5 km | | |
| **Construction and land owners permits** | *County construction license* | | *2%* | Percentage to be applied over labor and construction costs |
| | *Urban license* | | *2.5%* | Percentage to be applied over the total cost |
| | *Land owners permits* | | | |
| | Road and trenches | | 6€/m$^2$ | |
| | Typical roads width | 6 m | | |
| | Typical trenches width | 1 m | | |
| | Evacuation line – overhead cables | | 1€/m$^2$ | |
| | Typical width | 40 m | | |
| | Evacuation line – pylon | | 5€/m$^2$ | |
| | Used area per pylon | 100 m$^2$ | | |
| | Number of pylons | 33 units | | One pylon every 150 m |

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